Heat Network Zoning and the Alignment of Profit and Equity in District Heat Networks

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Challenge Statement

Achieving national net-zero targets requires the decarbonisation of heat. District heating is a proven decarbonisation option when supplied by low carbon or recovered heat sources, yet deployment across Europe is highly uneven. Uptake remains low in liberalised markets such as the UK, in contrast to coordinated municipal heat planning models that have supported higher penetration elsewhere[1] (for example, over 60% of households are connected to district heating in Denmark).

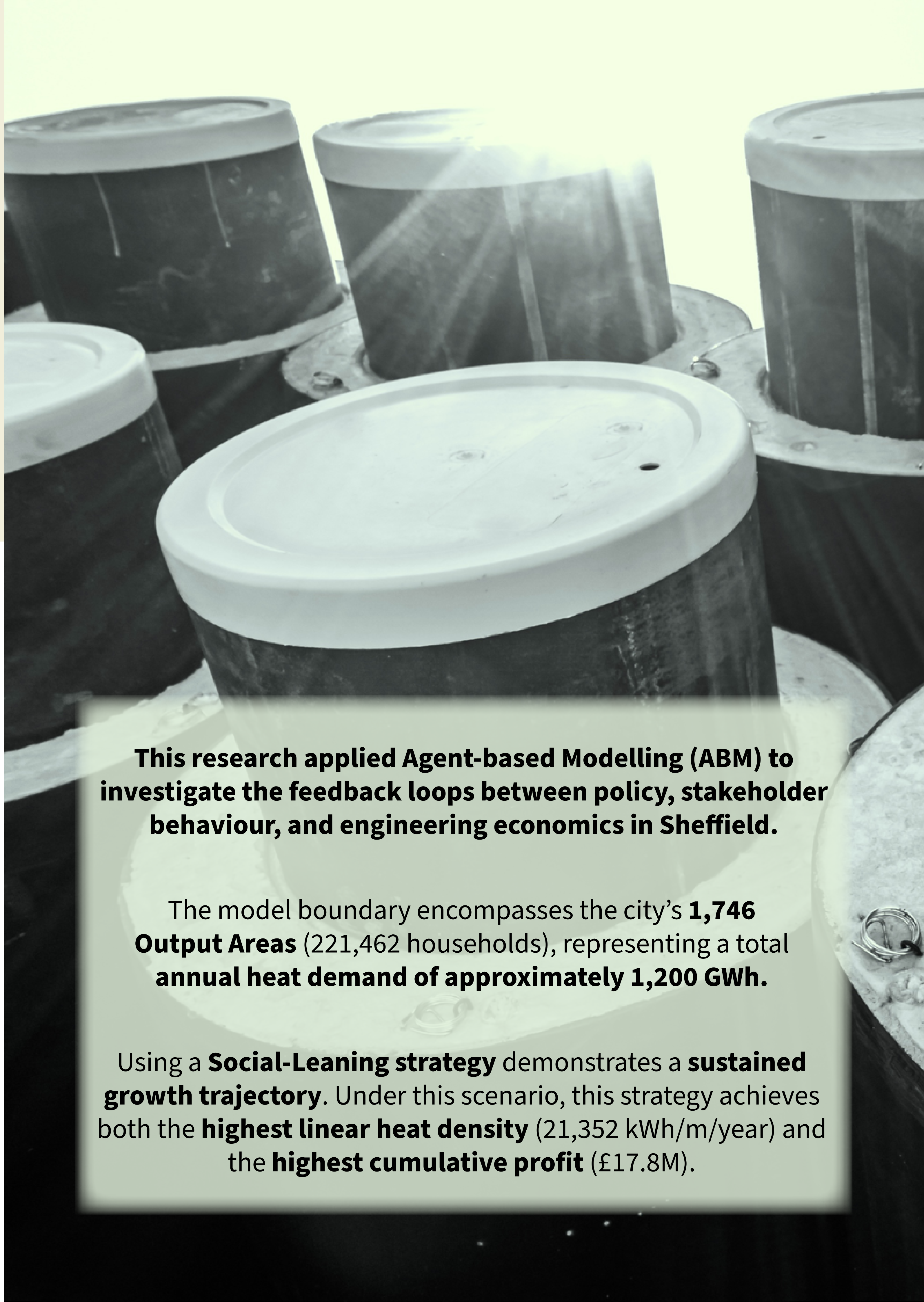
In liberalised markets, market-led rollout strategies can risk widening social inequality if less commercially attractive areas and customer segments are left unserved[2]. In response, governments including the UK are introducing policy frameworks and procedures inspired by more coordinated planning approaches, including mandatory heat network zoning[3] and area-based local energy planning[4].

The effectiveness of these top-down policies depends on how they interact with bottom-up stakeholder behaviour, resource allocation, and spatial constraints[5]. This interaction will be particularly important over the coming decade as heating policy and standards evolve to avoid locking buildings into costly or suboptimal heating pathways.

Response

This research applied Agent-based Modelling (ABM) as a means of investigating the feedback loops between policy, stakeholder behaviour, and engineering economics using the city of Sheffield as its case study. The city was selected for its diverse urban morphology, well-defined socio-economic geography, and its role as a participant in the UK Government's Heat Network Zoning pilot programme3 [12]. The model boundary

1 Hawkey, D. and Webb, J. (2014), 'District energy development in liberalised markets: situating UK heat network development in comparison with Dutch and Norwegian case studies.' Technol Anal Strateg Manag, vol. 26, no. 10, pp. 1228–1241
2 The Greenlining Institute (2019), 'Equitable Building Electrification: A Framework for Powering Resilient Communities'.
3 Department for Energy Security and Net Zero (2024), 'Heat network zoning: overview'.
4 Department for Energy Security & Net Zero (2025), 'Heat network zone opportunity report: Sheffield'.
5 Lockwood, M. and Devenish, A. (2024), 'Institutional context and the governance of heat transitions: The cases of the Netherlands and the UK.' Environ Innov Soc Transit, vol. 50, p. 100818.



This research applied Agent-based Modelling (ABM) to investigate the feedback loops between policy, stakeholder behaviour, and engineering economics in Sheffield.

The model boundary encompasses the city's **1,746 Output Areas** (221,462 households), representing a total **annual heat demand of approximately 1,200 GWh.**

Using a **Social-Leaning strategy** demonstrates a **sustained growth trajectory**. Under this scenario, this strategy achieves both the **highest linear heat density** (21,352 kWh/m/year) and the **highest cumulative profit** (£17.8M).

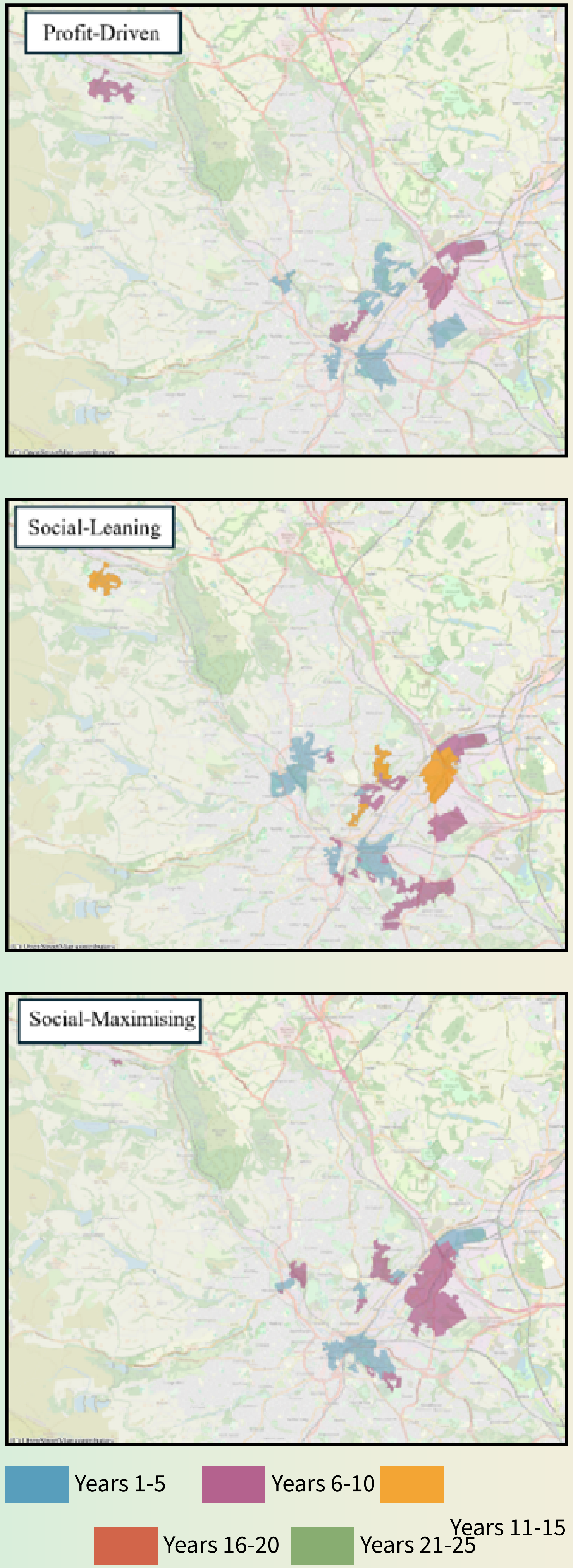


Figure 1: Temporal-Spatial Evolution of Network Infrastructure Under Different Operator Strategies

encompasses the city's 1,746 Output Areas (221,462 households), representing a total annual heat demand of approximately 1,200 GWh[6, 7, 8].

ABM was used to explore how competing planning strategies may shape spatially explicit network growth and equity outcomes in a UK case study context, comparing alternative operator investment priorities ranging from profit-driven to socially oriented objectives. The framework was also used to examine how stylised policy levers, such as heat network zoning, could influence development pathways over a 25-year simulation period (2025–2050), under two regulatory scenarios: a baseline market-driven case and a Heat Network Zoning case. The zoning scenario reflects current UK policy proposals, which introduce mandatory connection requirements for specific building types within designated zones[4].

The model explores six stylised operator strategies, represented by a single parameter (λ) that shifts investment priorities from purely profit-driven (λ=0) to strongly social-oriented (λ=5), with intermediate values representing more balanced approaches. These scenarios do not represent different organisations, but alternative strategic priorities applied within the same modelling framework.

Evidence and Outputs

The simulations identify two contrasting development pathways for district heat network (DHN) expansion under different operator strategies: early stagnation and sustained growth. Findings reflect stylised scenario simulations and illustrate mechanisms and feedback loops rather than real-world forecasts.

As illustrated in Figure 1, both the Profit-Driven and Social-Maximising strategies exhibit early stagnation, with no further network construction occurring after approximately Year 10 (an absence of orange, red, or green areas). Under the Profit-Driven strategy, deployment is limited to a small number of scattered networks that fail to achieve sufficient scale for continued growth and coverage.

6 Nomis (2021), 'Census 2021: Official labour market statistics'.
7 Department for Levelling Up Housing and Communities (DLUHC), EPC Datatables (2026), 'Energy Performance of Buildings Certificates: Live tables'.
8 Cambridge Energy (2025), 'Cambridge Housing Model (BEIS)'.

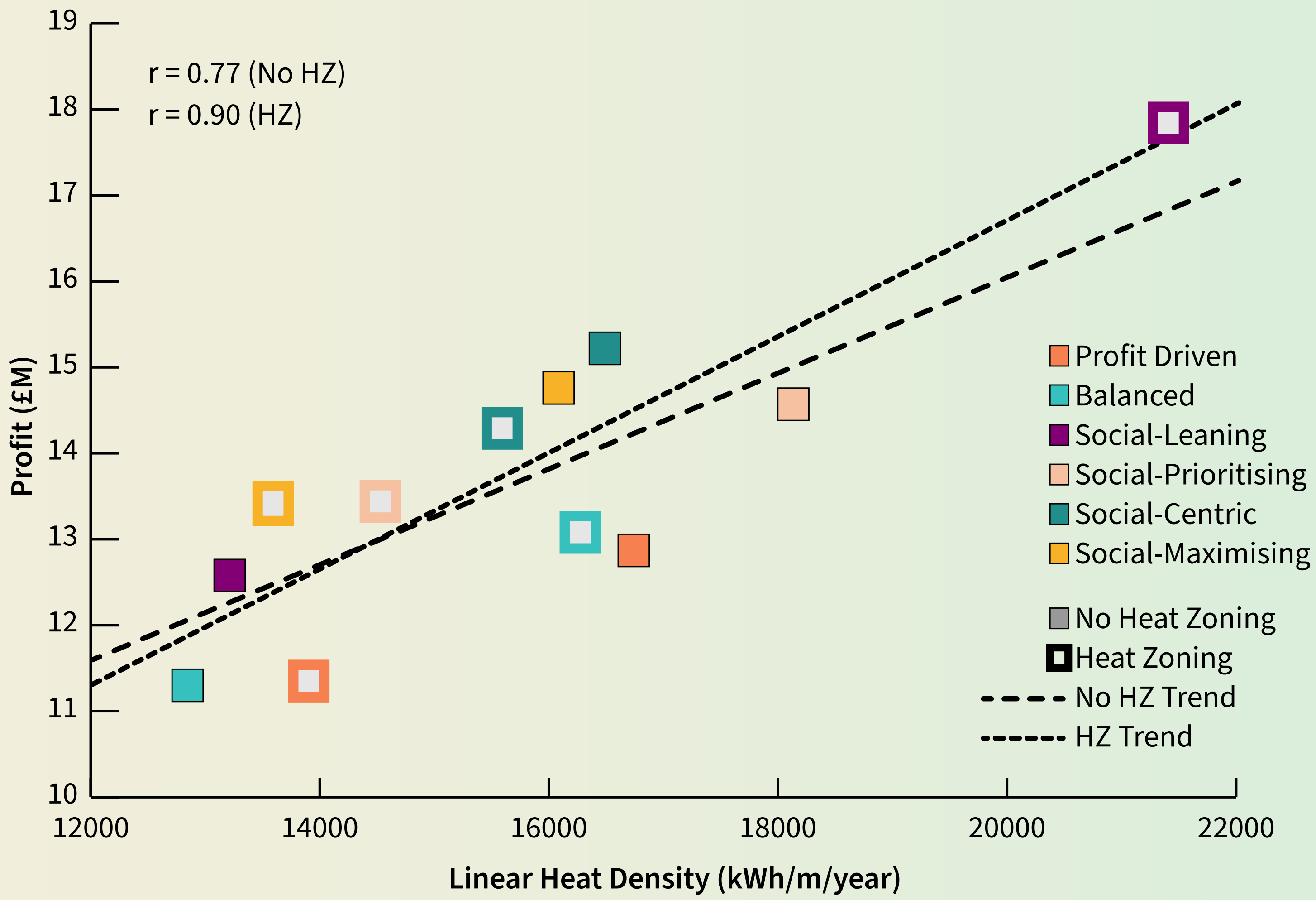


Figure 2: The Relationship Between Linear Heat Density and Financial Performance

In contrast, the Social-Maximising strategy produces an initial burst of expansion focused on high-deprivation areas, but this growth is not financially self-sustaining and subsequently stalls.

Only the Social-Leaning strategy demonstrates a sustained growth trajectory. Network expansion under this strategy occurs in multiple phases over the 25-year simulation, enabling the development of larger, more integrated networks that connect a broader range of urban areas. The mechanism in the model is that zoning increases demand certainty and scale, improving project viability and supporting continuous expansion. This reduces the tendency for purely profit driven strategies to stall due to insufficient early scale, and for purely social strategies to overextend into financially fragile buildouts. Under the zoning scenario, this strategy achieves both the highest linear heat density (21,352 kWh/m/year) and the highest cumulative profit (£17.8M) as shown in Figure 2. Cumulative profit is measured from the operator's perspective under assumed heat tariffs and costs in the model.

Figure 3 highlights how these operating differences translate into spatial equity outcomes. The Profit-Driven strategy predominantly routes infrastructure away from areas of high deprivation, resulting in fragmented networks that largely bypass higher-need communities. The Social-Maximising strategy concentrates deployment almost exclusively in the high-deprivation eastern sections resulting in two large, continuous networks that fail to expand and become isolated geographically from the rest of the city. By contrast the balanced strategy distributes infrastructure across the full socio-economic spectrum, with networks that serve both deprived and non-deprived areas within the same system.

Figure 4 illustrates a stylised household-level cost comparison under a scenario in which households are required to transition away from gas heating in 2035. The model compares the lifetime costs of individual heat pumps and access to a DHN over a 25-year period. In areas served by DHN infrastructure, households are modelled as facing lower lifetime heating costs relative to an equivalent household relying on a heat pump, with differences ranging from approximately £443 to £6,443 depending on location and assumed installation costs. In areas without DHN access,

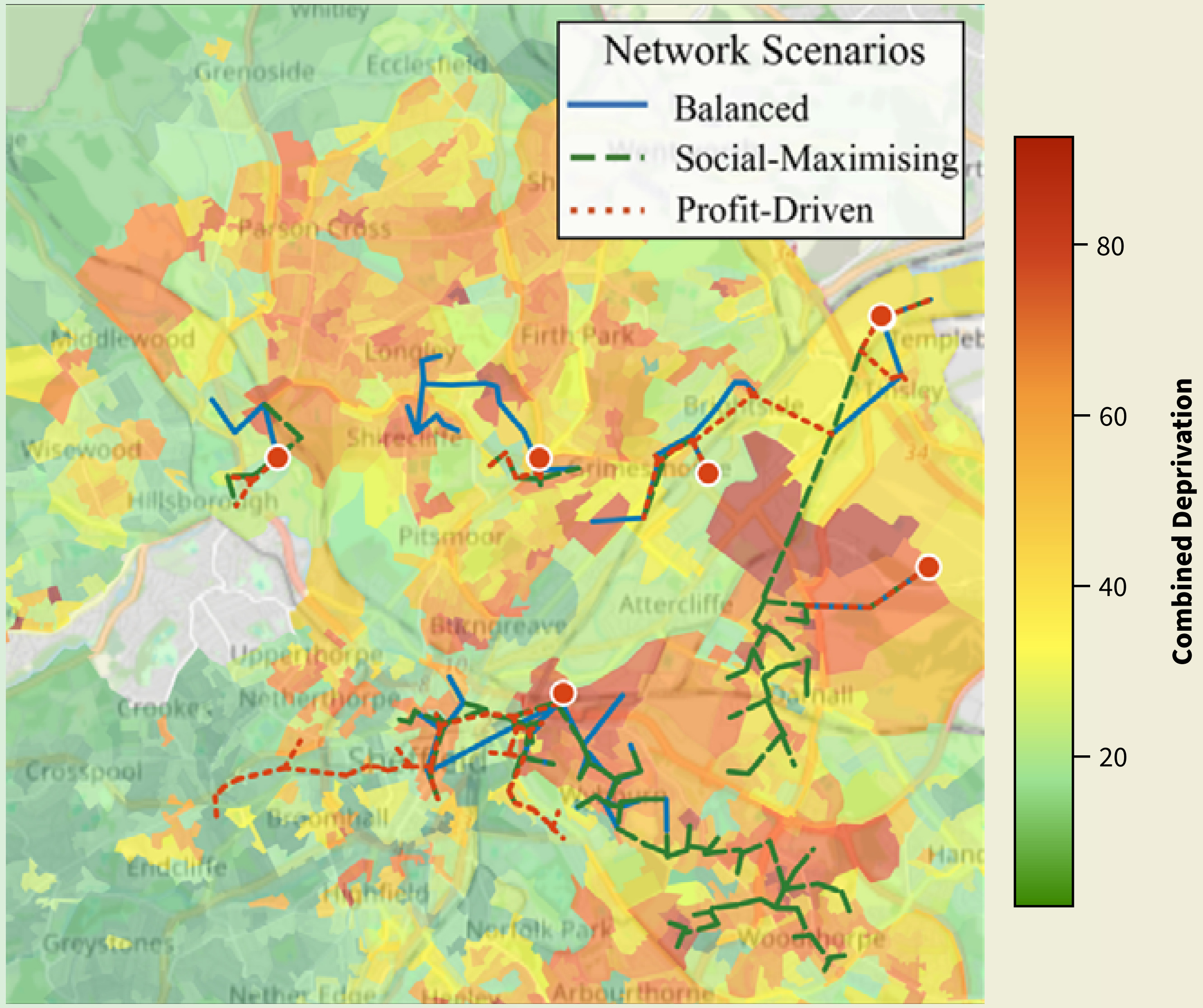


Figure 3: Spatial Distribution of Network Infrastructure Across Socio-economic Gradients

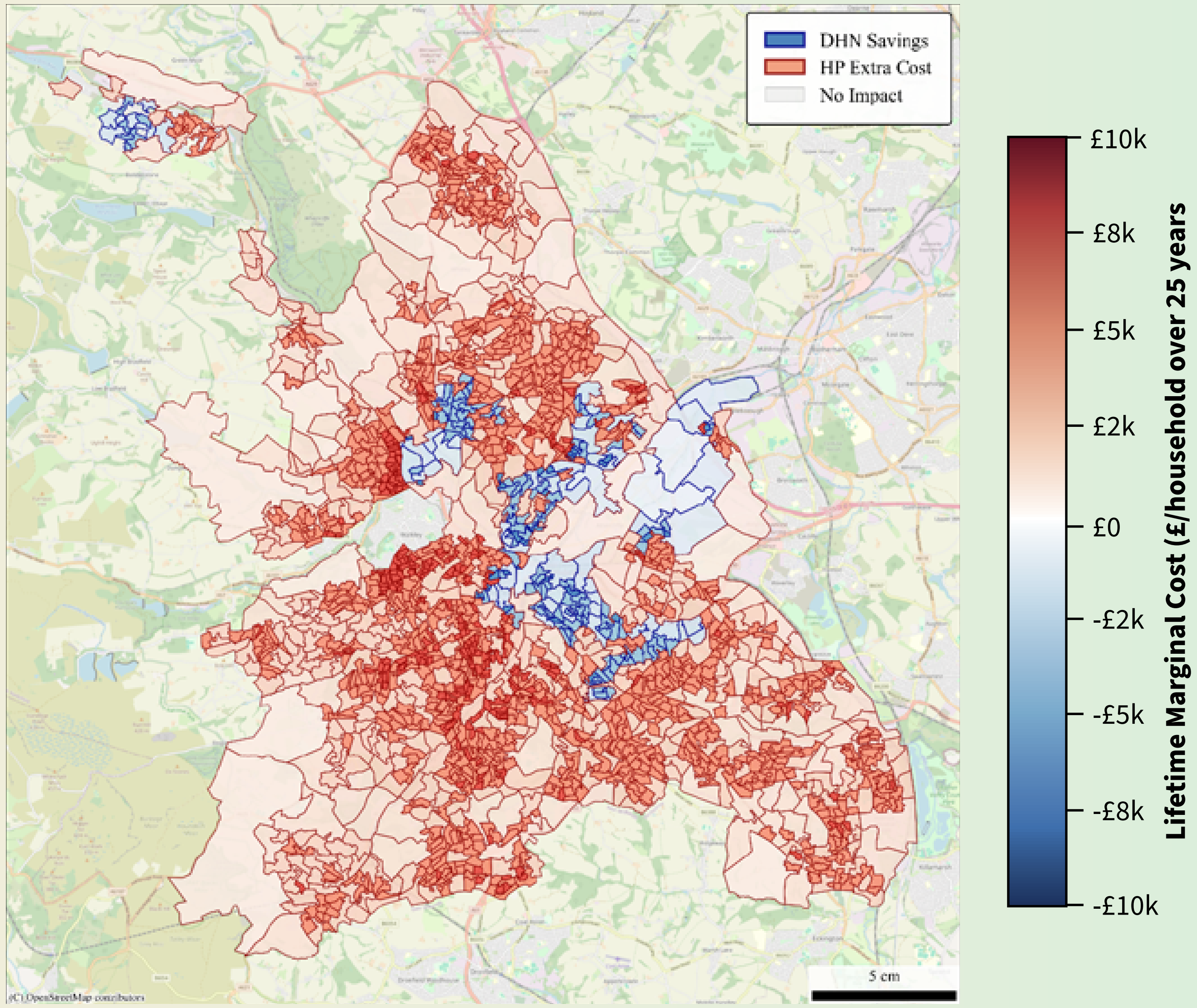


Figure 4: Illustrative Household Economic Impact of DHN Access Over a 25-Year Lifetime

households rely on individual heat pumps and face a corresponding opportunity cost relative to identical households with access to a DHN. These results are illustrative and reflect relative differences under the model's assumptions, rather than predictions of realised household savings. This comparison reflects household costs under assumed DHN tariffs and connection costs, and does not allocate wider system costs or distributional impacts beyond the household boundary.

Regional Policy Implications

The Sheffield case study indicates that coordinated spatial planning mechanisms, such as heat network zoning, can significantly influence how DHNs expand under different operator strategies and market conditions. Within the model, zoning alters investment incentives in a way that enables intermediate, social-leaning strategies to achieve both strong financial performance and broader spatial coverage, reducing the trade-off between profitability and social inclusion observed in uncoordinated market scenarios.

The analysis also highlights the potential for technology-neutral decarbonisation mandates to produce uneven, geographically determined inequities if deployed without coordination. Without planning mechanisms, commercially driven rollout may bypass less profitable areas, while early adopters of individual low-carbon technologies risk incurring higher lifetime costs or stranded investment as collective solutions later emerge.

Importantly, the results suggest that long-term financial sustainability and social equity are not inherently in conflict. Under coordinated policy frameworks, financially robust networks are better positioned to support wider inclusion through scale and cross-subsidisation. From a regional perspective, city-wide network growth emerges as a more meaningful indicator of social value than high connection rates within narrowly targeted areas.

Implications for South Yorkshire

- Use zoning to create demand certainty for anchor loads and high density corridors first, then expand into harder to serve areas once cashflows stabilise and use cross-subsidies.
- Define zoning alongside affordability and consumer protection measures, otherwise "mandated connection" can become politically fragile.
- Treat customer friction as a core delivery risk. Fund engagement and installation coordination should be seen as a programme, not a one off.

Limitations and Next Steps

Even with coordinated policy, social barriers remain important and effective delivery still depends on trust, disruption management, and service quality. Results are sensitive to assumed tariffs, subsidy levels, and household friction, so the absolute magnitudes are illustrative even where the directional effects are robust. Financial incentives alone are therefore insufficient; successful deployment requires ongoing engagement with customers and sustained focus on service delivery.

Future work could extend this analysis by incorporating additional real-world complexities, including multiple competing operators, evolving technology costs, fuel price volatility, and adaptive consumer preferences. These extensions would further support the translation of strategic insights into practical policy design.